# F#2 diffractive lens, 17 micron thick, 250 mm diameter, phase only Strehl 0.32 (NIF & DARPA)

LLNL Diffraction optics Group; Michael C. Rushford rushford1@llnl.gov, Nguyen Hoang T. nguyen7@llnl.gov
Advance Reproduction Corp (photomask), Michael DeBruyckere (m.debruyckere@advancerepro.com) & NeXolve Corp (Polymer replication) Patrick, Brian Brian.Patrick@nexolve.com; Dr. Brandon Farmer

## 4 level diffraction lens technology path

**This 4 level diffraction lens accesses the technology path to a disposable satellite 1 meter diameter lens. Measured average diffraction efficiency over 90% of clear aperture is 32% with maximum local diffraction measured to be 81%. Low average diffraction efficiency is a result of the mask-less photo plotting overlay error.**

Effect of fabrication errors on multilevel Fresnel zone lenses
OPTICAL ENGINEERING / April 1994 / Vol. 33 No. 4/ 1229

Electromagnetic theory and design of diffractive-lens arrays
J. Opt. Soc. Am. A/Vol. 10, No. 3/March 1993

**Fabrication of a multi-level lens using independent-exposure lithography and FAB plasma etching**
**Do KyunWoo1** J. Opt. A: Pure Appl. Opt. **10** (2008)

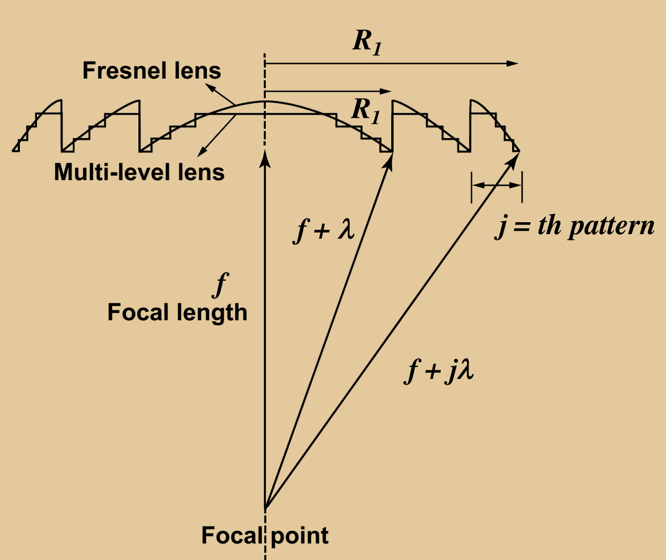



Figure 2. Multi-level lens in the Fresnel zone construction.

Figure 2 shows the relationship between the radius $R_J$ of the $j$th pattern and the focal length of the Fresnel lens as well as the scheme of the multi-level lens in a Fresnel zone construction. The radius $R_J$ can be easily calculated geometrically using equation (3) [13]:

$$R_J = \sqrt{2j\lambda f + (j\lambda)^2} \qquad (3)$$

Based on equation (3), the radii of each level in each pattern can be determined:

$$R_{J,1} = \sqrt{2\left(j-\frac{3}{4}\right)\lambda f + \left(\left(j-\frac{3}{4}\right)\lambda\right)^2}$$

$$R_{J,2} = \sqrt{2\left(j-\frac{2}{4}\right)\lambda f + \left(\left(j-\frac{2}{4}\right)\lambda\right)^2} \qquad (4)$$

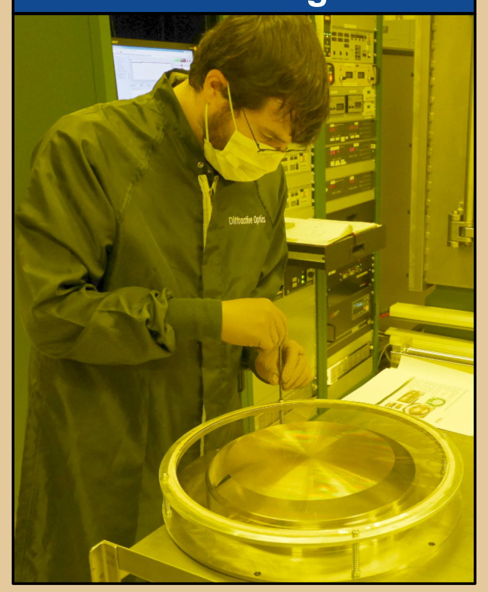
$$R_{J,3} = \sqrt{2\left(j-\frac{1}{4}\right)\lambda f + \left(\left(j-\frac{1}{4}\right)\lambda\right)^2}$$

$$R_{J,4} = R_J = \sqrt{2j\lambda f + (j\lambda)^2}$$

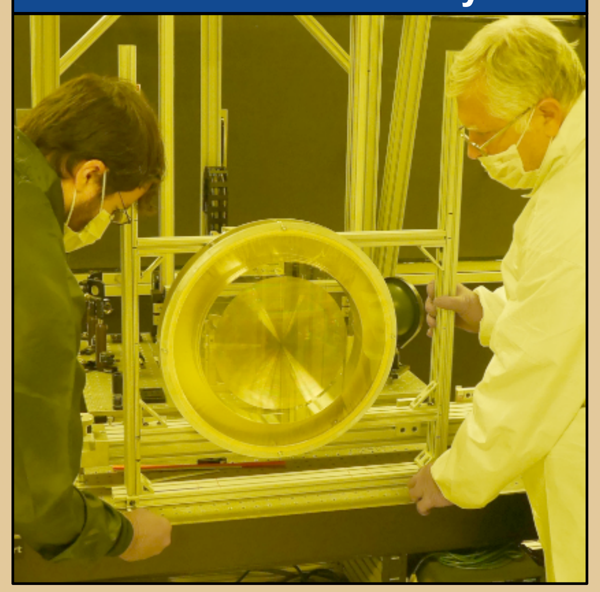
$$d = \frac{(N-1)\lambda}{N(n_{lens}-1)}$$

Where $R_{J,n}$ is the radius of level $N$ in the $j$th pattern, $\lambda$ is the wavelength of the incident light, $d$ is the thickness of the $N$-level lens and $N$ is the number of levels

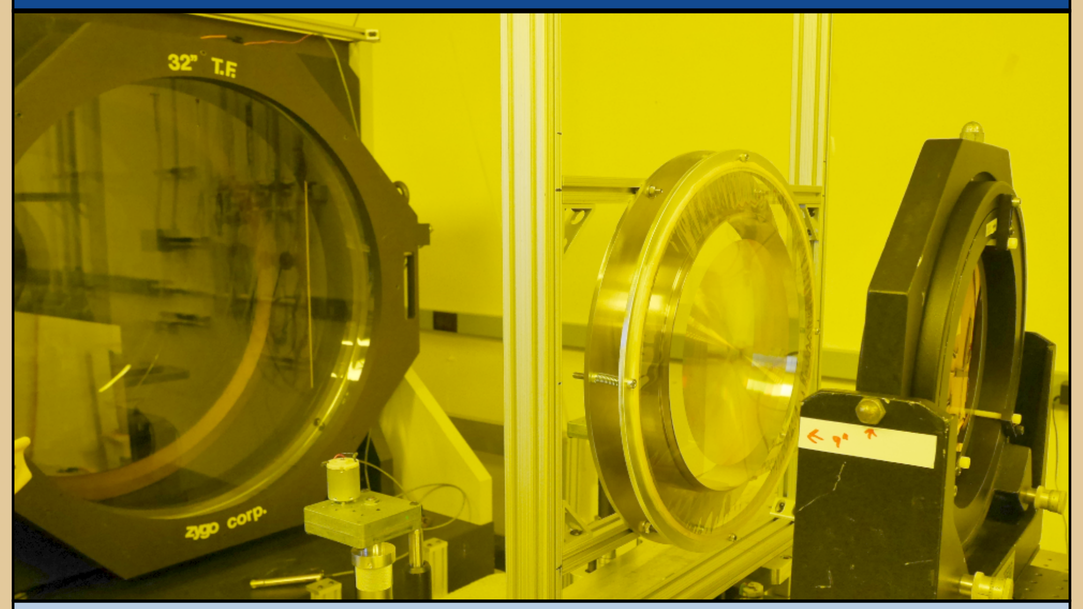
### Membrane lens mounting



### Photometer measured diffraction efficiency



### Lens tensioning just enough to minimize surface ripples



Fizeau wave front via 400 mm radius gold coated reference convex sphere, beam double passing lens

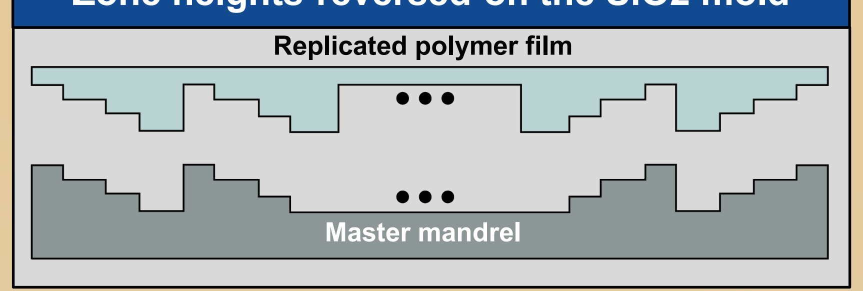
### Python and 1D simulation tests, write photo plotter zone edge Excel files

LLNL designed & made the SiO2 mandrel

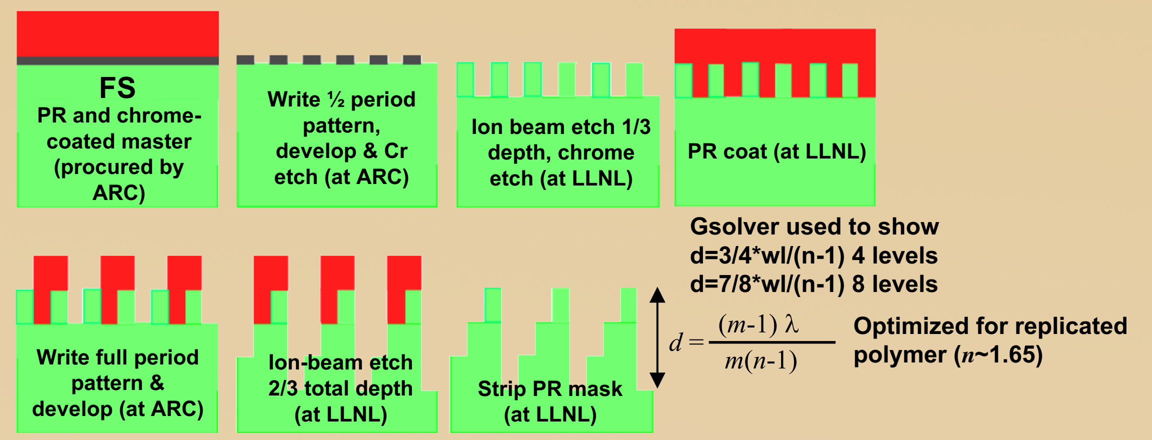
Advance Reproductions did the lithographic exposure

NeXolve made mount and replicated SiO2 mandrel with 17 micron thick film @ optical thickness variation < 0.15 waves at 1053 nm.

**Zone heights-reversed-on the SiO2 mold**




### 4-level replicated membrane process flow

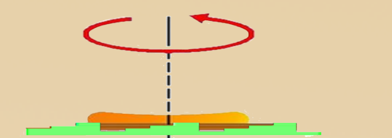



Gsolver used to show
d=3/4*wl/(n-1) 4 levels
d=7/8*wl/(n-1) 8 levels

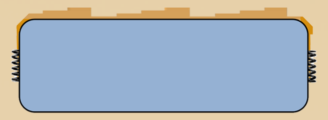
$$d = \frac{(m-1)\lambda}{m(n-1)}$$

Optimized for replicated polymer ($n$~1.65)

d=0.001053 [mm]/0.65 = 0.00162 mm
APPLIED OPTICS / Vol. 33, No. 5 / 10 February 1994 In most kinoforms, the maximum relief depth Is chosen such that, at the chosen design wavelength, the maximum phase modulation introduced by the kinoform Is 2pi 'J. A. Jordan, Jr., P. M. Hirsch, L. B. Lesem, and D. L. Van Rooy, "Kinoform Lenses," Appl. Opt. 9, 1883 (1970).

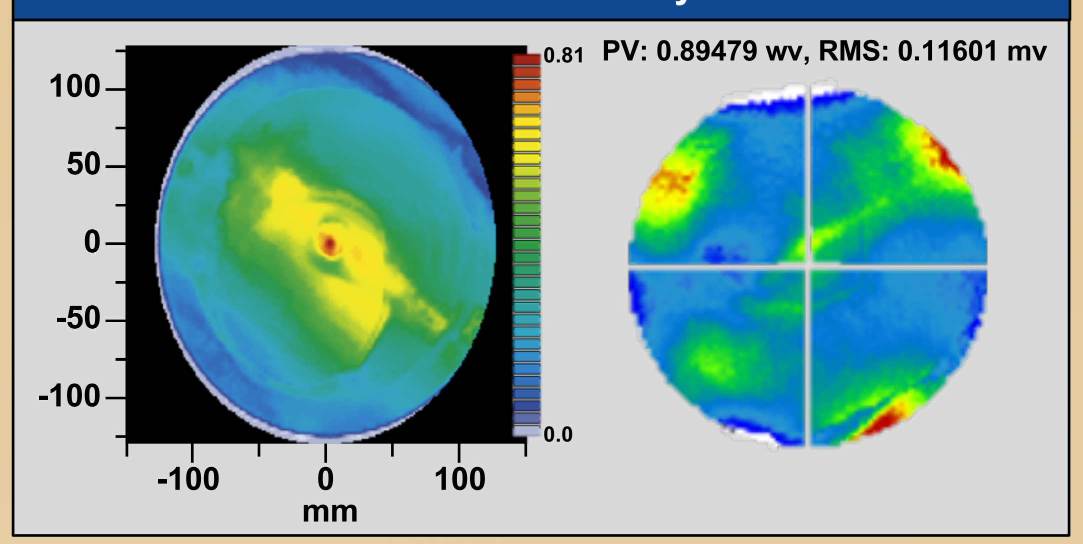


Spin cast & cure film on master mandrel (at NeXolve)

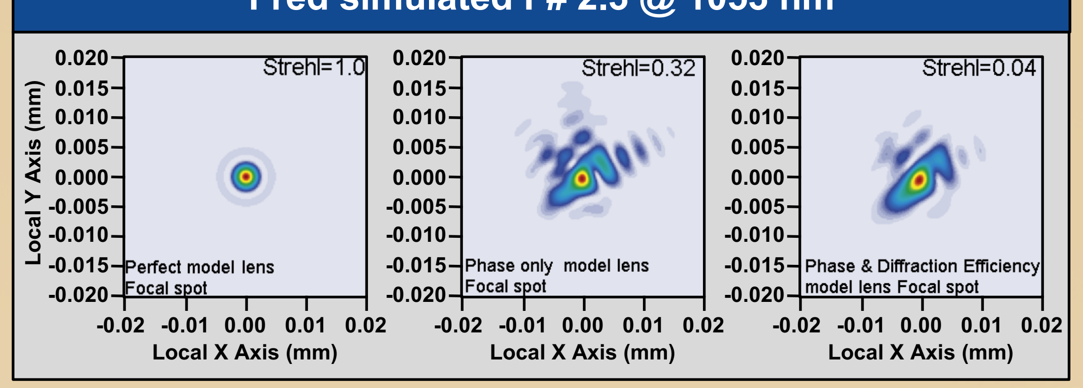


Release membrane from master, mount and tension onto optical-flat hoop (at NeXolve)

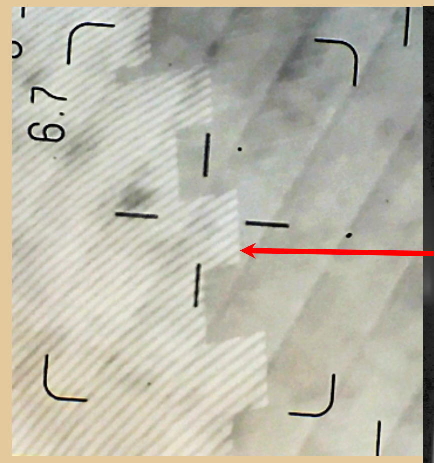
### Measured Diffraction Efficiency & Wave Front




### Fred simulated F# 2.3 @ 1053 nm




## Lithography Issues

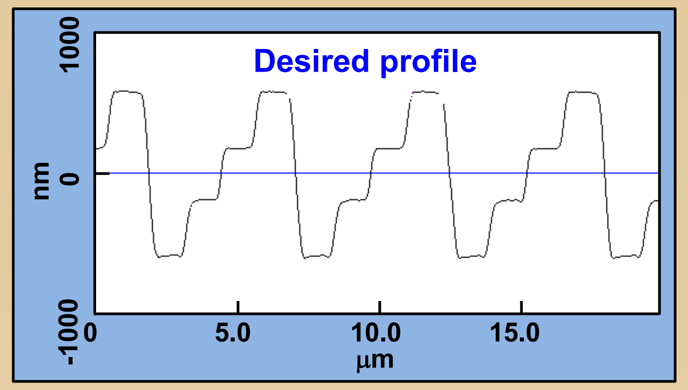


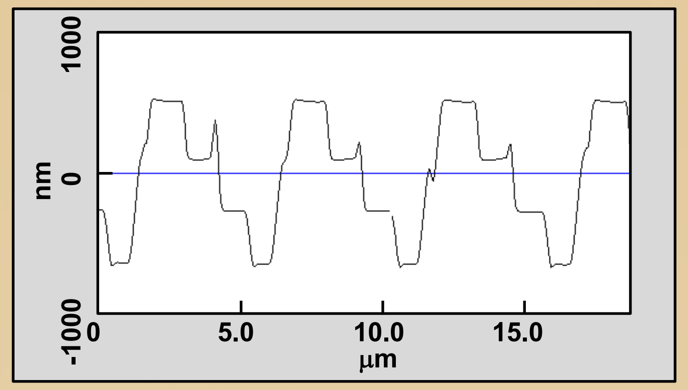
The 45 degree artifact view by microscope. Software caused stitching dado boundary. This first mask write dado did not cause a measurable diffraction efficiency nor wave front artifact in the finished lens. The outermost lens line widths of 1.2 micron jumps 62 nm across the dado as measured by a 480 nm Keyence microscope.

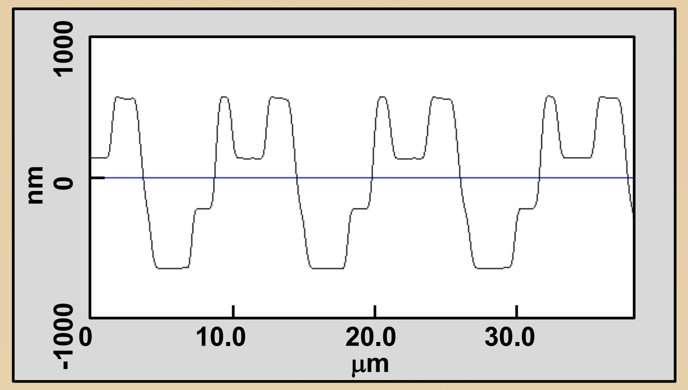

1st resist write on glass plate viewed by flash light relay reflection into a digital camera. Shown is diffraction/reflection efficiency discontinuities at 45 degrees and annular outer zone where the density of photo exposed dots pattern making up a lens lines changes by software control choices, maybe also photo resist clearing difficulties, no one knew these issues would occur before we tried. We accepted these error and proceeded to the overlay of the second writing layer.

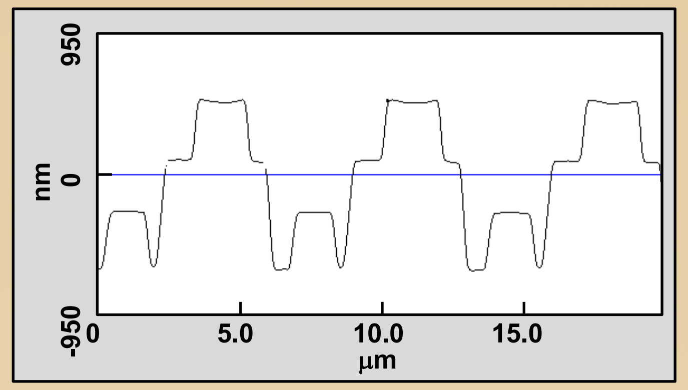
**Another attempt on a newer photo plotter may offer better resulting overlays, need to try to know**

### Examples of lithography overlay error between 1st and 2nd write measured on master optic



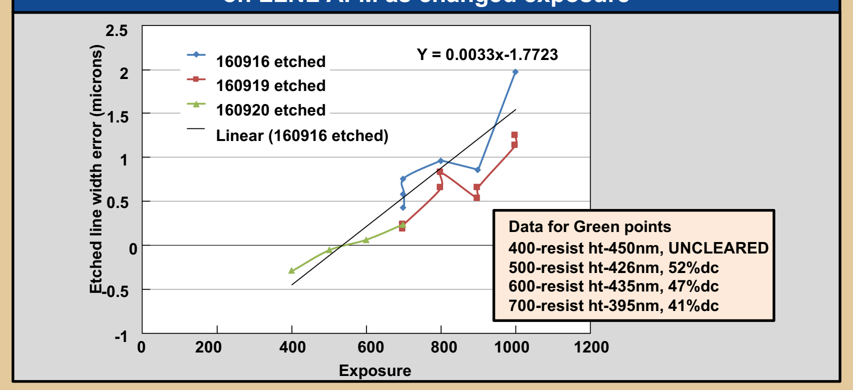

## Future Work

### Proposed path forward

- Improve mask lithography
  1. Advance Reproduction Corporation took delivery of a next-generation photomask plotting system in late 2016. The new system is capable of achieving 0.75 µm minimum feature with 0.25 µm overlay accuracy for multi-write applications over 1.1 meters. In addition, the expanded capabilities offer 256 greyscale technology. This tool would offer a minimum of 2X better accuracy than previously generated optical patterns.
  2. Infinite Graphics offers a grayscale photomask lithography process with would eliminate the need for a multi-write process. This however would require internal development efforts to establish a grayscale plasm etch process, which we have briefly worked on in the past with some success. This approach has the possibility of providing the highest diffraction efficiencies.
- Improvements to diffraction efficiency through test and analysis
  1. Meticulous metrology and characterization of the membrane is needed to better understand what the issues are. This task would require mounting the membrane to a thick backing substrate. NeXolve can modify the polymer chemistry for improved replication quality if testing shows it is required.
  2. Evaluate utilizing commercially available 100 micron thick glass substrates to mitigate the issues with the replicated polymer material.

### Map out exposure linewidth @ plotter facility

**Cleared resist and plasma etched line width error measured on LLNL AFM as changed exposure**



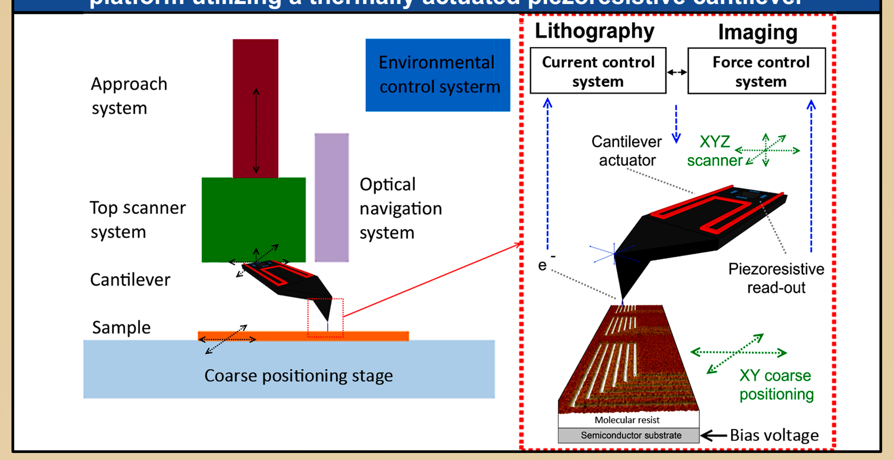

### Need Lithography and registration improvements

- AFM measurements at the photo plotter to inspect test plate exposure and developed line widths before writing on larger part. AFM and reflected light inspection to show all resist is cleared down to the glass.
- In the corners where alignment marks are now placed and microscope registration done for the second write, make "overlay check" exposure and development marks then AFM measurements so to further check & refine the overlay offsets for the second write.
- Record location / orientation of measurements to a "Gamma Pattern" at lens center on each processing and measurement system, for debugging purposes.

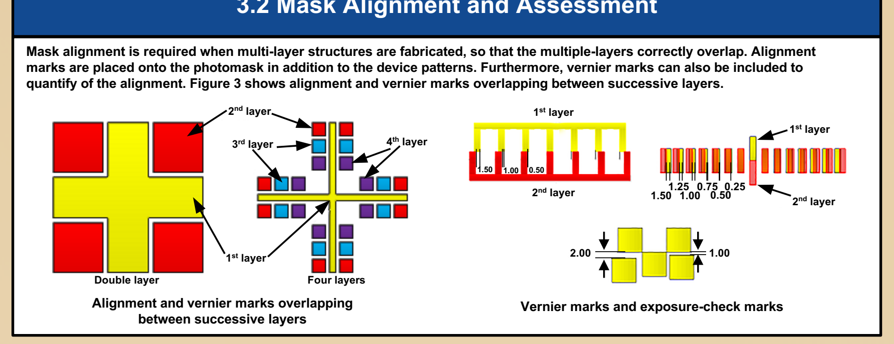
### Do these things at the photo plotter

J. Micro/Nanolith. MEMS MOEMS 14(3), 031202 (Jul–Sep 2015)

**Schematic layout of the closed-loop scanning probe lithography (SPL) platform utilizing a thermally actuated piezoresistive cantilever**




**3.2 Mask Alignment and Assessment**




P2719610

LLNL-POST-000000